wing for days and nights together without intermission; many fishes require perpetual motion in order to preserve their equilibrium, while other pelagic forms appear to be on the move for long periods of time without flagging, — all these cases necessitating oft-repeated movements, which call for far more serious strain on the muscles than the mere extension of the wings during the act of soaring.

The strain on the extensor muscles at such a time can be but trifling, compared to the strain on the levators and depressors of such a bird as the albatross, whose weight of nine to fifteen pounds is supported by two levers of the third class, five to seven feet in length; and yet no bird makes longer flights than this wanderer of the southern seas, who has no special device to keep his wings outstretched.

These instances are brought forward, not to disprove the fact that a device to ease the muscles in soaring may not exist, but to show that there is apparently not the slightest need for it.

In regard to the interlocking of the primaries, which unquestionably takes place, is not this the result of their emargination, and consequent failure to glide smoothly over one another, rather than the end to be accomplished by this cutting-away of the feather toward the extremity?

This view of the case is borne out by the fact that the longer, more flexible ulnar border of the primary naturally gives at each stroke of the wing, thus catching in the radial portion of the feather immediately behind it, whether the bird wishes it or not.

Moreover, during the act of soaring, the wing is expanded to its utmost, and the tips of the primaries widely separated, while in a fresh specimen of *Buteo borealis* no locking is possible until the wing is partially closed. This would seem to be conclusive as regards the importance of the locking of the primaries as an aid in soaring; although there remain the facts that some birds who soar to perfection — such, for example, as gulls, cranes, storks, and the frigate-bird — do not possess emarginate primaries, while others, like some owls and flycatchers, have emarginate primaries but do not soar.

Professor Trowbridge's comparison of the wing to a flat card is hardly felicitous, and his statement that it would be in a state of unstable equilibrium but for the locking of the primaries would seem open to serious doubt.

One absolute requisite of a wing is that the anterior margin should be rigid, and the posterior border flexible, — a requirement which is met toward the extremity of a bird's wing by bringing the quill close to the radial margin of the feather, leaving a posterior pliable edge.

Now, if the primaries are interlocked, a rigidity is created toward the ulnar border of the wing, which would thus become more card-like and unserviceable than if the primaries did not lock.

A pertinent question that might be asked of Professor Trowbridge, is, Why, if the "long primaries present a serious resistance . . . when a bird is soaring," do all birds that soar or sail possess just such primaries, while the corresponding feathers in birds which do not soar are short?

One feature in the wings of birds pre-eminent for soaring abilities, e.g., the *Vulturidæ* and *Falconidæ*, has not been touched upon in this discussion, so far as I am aware; and this is the fact that when the wing is extended to its utmost, as it invariably is during soaring, the metacarpus and phalanges are not in line with the ulna, but are bent forward of it. By this arrangement some of the muscles and tendons that ordinarily act in flexing the wing are brought upon the dorsal surface of the bones, and thus have their power of flexion weakened, or possibly even made to aid in the automatic extension of the wing. If, now, a bird with wings thus spread be so killed that there is no perceptible shock or nervous start, the bird may remain with outstretched pinions and sail gradually downward, — exactly such a case as Professor Newberry describes.

In conclusion, I can but regret that I have no facts to adduce that will throw any light on the problem of flight, as it is far easier to find fault with any theory than to suggest a better, and purely adverse criticism must always seem more or less ungracious.

FREDERIC A. LUCAS.

Washington, D.C., Jan. 16.

Binocular Combinations upon Disparate Retinal Points.

EVERY one is familiar with the fact that Wheatstone and many subsequent investigators have explained the binocular perception of solidity by the theory of the 'fusion of images upon disparate points,' as they are called, in the retina. They have generally denied the original possibility of a monocular perception of solidity and distance; and hence, when certain plane figures were stereoscopically combined, the apparent solidity of the resulting single figure suggested its explanation in accordance with what had previously been supposed of the mathematical relation between combination and convergence. Thus Wheatstone's view may be illustrated by the following figure. It is well known that the stereoscopic combination of these figures, although making a plane image only upon the retina and representing only a plane surface externally, nevertheless produces the appearance of a solid body. Previous theories of vision had maintained that single vision took place upon corre-

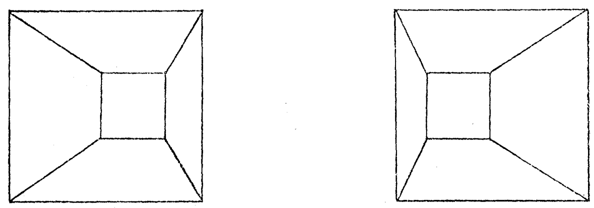

FIG. 1.

sponding points of the retina, and double vision upon disparate points. Now, as the mathematical construction of the case would not allow the inner figures and lines to fall upon exactly corresponding points, the apparently single character of the image in stereoscopic combination was most naturally explained by saying that fusion took place upon disparate points; and hence when the perception of solidity, or relatively different distances between the larger and smaller figures, uniformly accompanied this kind of fusion, it was naturally ascribed to that process as its cause. Whether such a fusion really takes place or not, has been hotly contested, and we wish here to present a few new considerations to show that it does not occur, notwithstanding the strongest apparent evidence of our actual perception of it.

To make the argument clear, a few words will be necessary upon what is meant by 'corresponding' and 'disparate' points. As indicated, they denote the points upon which respectively single and double vision takes place. But the second term has two very distinct applications, — one binocular, and the other monocular. It is

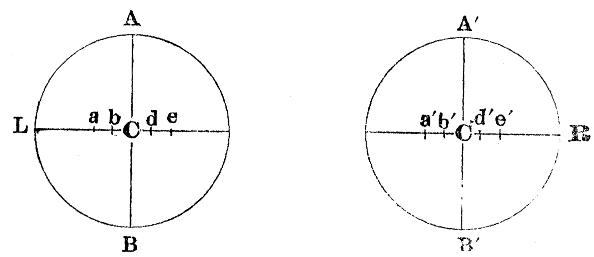

FIG. 2.

this last fact and its implications which most investigators, and among them Wheatstone, seem to have ignored. But the importance of taking it into account will be evident from the following considerations. Take the circles *R* and *L* to represent the retinal surfaces of the two eyes. Divide each retina into halves by the vertical meridians *AB* and *A′B′*. Draw also the horizontal meridians in which lie the points *a*, *b*, *c*, *d*, *e*, and *a′*, *b′*, *c′*, *d′*, *e′*; *c* and *c′*, at the intersection of the vertical and horizontal meridians, represent the *fovea centralis* of each eye. Now, the vertical meridian divides each eye into halves, that correspond to the opposite halves of the other eye. Thus we have what are called the nasal or inner, and the temporal or outer halves of the eyes. The nasal halves of each eye are said to 'correspond' to the temporal halves of the other eye. How this will appear can be seen by superimposing one circle upon the other; and the points *a* and *b* in the temporal half of the left eye, *L*, will coincide with *a′* and *b′* in the nasal half of the right eye, *R*; and *d* and *e* in the nasal half of the left will coincide with *d′* and *e′* in the temporal half of the right eye. By

calling these 'corresponding' halves, we mean that they have the same function of localization; that is, that they are constructed for seeing the same object, at the same point in space, at the same time, assuming a given state of fixation and the proper position of the object. Thus one image of an object falling upon a in the left eye, L, and the other upon a' in the right eye; or upon b in the left, and b' in the right eye; and so on, — will make the object to appear single and in the same place. Hence they are called 'corresponding' points. But if one of the images falls upon a, and the other upon b' or any point between that and a', which may happen according to the position of the external object, there will appear to be two objects. This is because all other points than a' are 'disparate' in relation to a. So with b and c', or c and d'. Thus, while every point in a temporal half is a 'corresponding' point to a given point in the nasal half of the other eye, it is 'disparate' to all other points. This is the binocular use of the term. But since the temporal halves of the two eyes are non-corresponding halves, the points a, b, d', and e' are also 'disparate.' Now, in the monocular retina all the points are 'disparate' in relation to each other; that is, combination never takes place. Hence a, b, c, d, and e, or a', b', c', d', and e' are respectively 'disparate' in relation to each other monocularly considered. Then, since the temporal half of the right eye corresponds to the nasal half of the left eye, and the two are thus identical in visual functions, a and d', or b and e', are 'disparate' in relation to each other in precisely the same sense as a and d, or b and e, in monocular vision. This is the monocular use of the term. Now, since fusion of images never takes place in monocular vision (say, when separate images fall upon a and b, b and c, or a and d, and so on), it can never take place when the two images fall upon non-corresponding halves of the retina (say, both upon the temporal, or both upon the nasal halves; that is, upon b and d', a and d', or b and e'), any more than they would upon b and d, a and d, or b and e, and so on. The reason for this is plain. Each eye forms binocularly only half an eye, so that the temporal half of one is identical in function with the nasal half of the other. This being the case, the non-corresponding halves of the binocular eye form a monocular eye. Experiment will show this to be the case. Hence stereoscopic images falling both of them in the temporal, or both of them in the nasal halves of the binocular eye, will appear precisely as if one of them fell in the nasal and the other in the temporal half of the monocular eye, or as if both fell upon separate points in any one half of the monocular eye. Thus the images in the temporal halves a, b, and d', e', can no more combine than if they were a, b, and d, e'. Hence a, b, d', e', are monocularly 'disparate;' so also d, e, a', b'. Now, since monocular combination of 'disparate' images never takes place, we can demonstrate that it can never take place in stereoscopic combination; at least, where the figures to be combined are such as Wheatstone's original illustration represented: namely, two lines which indicate opposite inclinations to the median plane. This is shown in the following lines, where A and B, the upper ends of the lines, will fall upon temporal halves of the retina when C and D fall upon the fovea, and yet fusion is as apparent as if it were real. The lower ends fall upon the nasal halves, and fusion is also apparent; the total resultant being a line with the upper end nearer the observer than the lower, and apparently upright or at an inclination to the plane of the paper. But it is effected by non-corresponding halves of the eye.

FIG. 3.

To illustrate this, take Fig. 4, R and L representing the two eyes. Let A and B represent two figures farther from the median line EF than C and D. A and B may represent the upper ends of the lines in Fig. 3, and C and D the centres; both together forming a plane geometrical outline for a stereoscopic figure such as Wheatstone employed. Take E for the point of fixation before combination, so that we may suppose A, B, C, and D to lie in the horopter. c and c' are the *foveæ centrales;* and when the eyes are fixated for an object at E, its two images will fall, one upon c and the other upon c'; while those of A will fall upon e and e', of B upon a and a', of C upon d and d', and of D upon b and b'. Now, a and a', b and b', c and c', d and d', e and e', being corresponding points, the several objects will be seen single while they are in the horopter; but the position of their images upon the retina must be noticed before indicating the effect of stereoscopic combination. The images of each object fall upon corresponding halves of the retina; but the images of A and B compared, also of C and D compared, fall upon non-corresponding halves of the retina. Now, in stereoscopic combination the object is to make A and B, or C and D, appear to coincide respectively; that is, appear upon the fovea. This may be done by converging or by diverging the eyes. But this can be effected only by fusing one image of A or C in the one eye with the image of B or D respectively in the non-corresponding half of the other eye. By convergence the fusion will be of images at present in the temporal halves; by divergence, of images in the nasal halves: that is, by the former combination, must be of extra-foveal, and by the latter of intra-foveal, images. a and b, and d' and e', are extra-foveal, because they lie in the temporal halves: d and e, and a' and b', are intra-foveal, because they lie in the nasal halves of the eyes. Now, if we converge the eyes so as to bring the image of C and D into the fovea, it is evident that the combination takes place only by what are extra-foveal images when the point of fixation is E. Convergence to produce combination of C and D requires a new point of fixation in the median line at the intersection of the lines which represent the course of light from C to d', and from D to b. When this is effected, the foveæ c and c' are shifted, the former to b and the latter to d', to receive the images at those points. But thus, while the images of C and D are fused in the fovea, those of A and B still fall upon extra-foveal points as far from the new position of c and c' as a is from b, and e' from d'. But being both extra-foveal, they fall in temporal and therefore non-corresponding halves of the retina. In Wheatstone's experiment, Fig. 1, these would represent the larger squares, and the apparent combination represented in the base of a visibly solid figure thus perceived is explained by 'fusion upon disparate points.' But being extra-foveal, and in the temporal or non-corresponding halves of the retina, these points are not binocularly, but monocularly 'disparate,' and hence the fusion claimed for them is as impossible as if it were claimed for the points a and b, or a and e, or

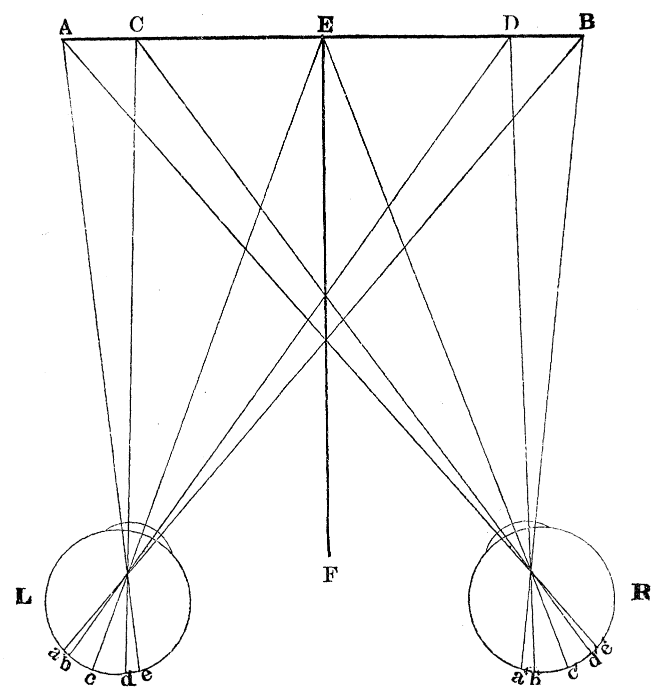

FIG. 4.

any two points in monocular vision. Images upon different sides of the fovea in monocular perception never combine, and are never supposed to combine. Now, supposing C and D in the foveæ c and c' by convergence, and keeping in mind the fact that the temporal half of the right eye in binocular perception corresponds to the nasal half of the left in monocular perception, the images of A and B, while they fall in non-corresponding halves, occupy positions visually the same as if they fell upon non-corresponding halves in monocular perception, the temporal and nasal; and hence, superimposing L upon R, e' would fall as far from the fovea in the nasal half as a from the fovea in the temporal half of the left eye L: that is, the images of A and B, a and e', visually fall upon opposite sides of the fovea, and can no more combine than separate images in monocular perception.

The same general result is obtained if we combine C and D by diverging the eyes; that is, by focusing the eyes in the median line beyond the point E, or beyond the stereoscopic figures. The eyes are thus turned outwards, so that the fovea in each case must be shifted inward from c to d, and from c' to b'. Combination of C and D will thus be attained by intra-foveal images, — such as are intra-foveal while the point of fixation remained at E. But when d and b' are brought into their corresponding fovea, e and a' still remain intra-foveal at distances from the fovea equal to that between d and e, and a' and b'. By the same argumentation as before, it can be shown that the images of A and B, respectively e and a', cannot combine. Thus, being both intra-foveal, they fall upon points in the nasal halves of the two eyes. These are binocularly non-corresponding, and therefore monocularly complementary halves of the retina: hence falling upon e and a' in binocular vision is the same as occupying opposite sides of the fovea in monocular vision, and so combination will be impossible. This shows the importance of observing what is implied by the term 'disparate.' As long as we conceive the term in its binocular application, there would be some reason for supposing combination upon them under the circumstances described. But adjustment by convergence and divergence, the former for extra-foveal and the latter for intra-foveal images, requires us to think of 'disparate' in its monocular application; and in that case we must either deny the possibility of combination upon them, or abandon the whole theory which makes a nasal half of one eye correspond to a temporal half of the other; for, if 'disparate' points in monocular perception may admit of combination, a nasal half may correspond to a nasal half, and a temporal to a temporal half, of the retina. This has never been assumed to be possible.

Of course, 'intra-foveal' and 'extra-foveal' are used with reference to the vertical meridian, and not the horizontal meridian, as Fig. 4 would seem to imply. In the last figure A and B represent positions relative to the vertical meridian of any objects in the temporal halves of the retina, and hence they may be above or below the horizontal meridian in which they really lie, according to the inclination of the lines to the median plane. The modification for the nasal halves of the retina can be supplied by the reader. It is evident from this that this demonstration does not apply mathematically to Fig. 1, where the apparent fusion is of binocularly 'disparate' points, although, taken in the *total* sense for *localization*, it will apply. But it is combination, not localization, that we are discussing.

If the stereoscope is used to effect the combination, the perspective noticed in convergence with the naked eyes is reversed, and is identical with that effected by the divergent movement to produce combination. The reason for this may be briefly stated. The partition between the lenses lies in the median line, and hence cuts off the extra-foveal images entirely. Combination has therefore to be effected by the intra-foveal. With this statement of the conditions, the argument could be carried out as before.

But the reply to our position that stereoscopic combination upon 'disparate' points must be impossible, will be the very plain one that it contradicts the *facts* of actual vision; that we can actually see the combination to have taken place; and, since it cannot have been upon corresponding, it must have been upon 'disparate' points. There are two replies to this, and, in addition, an important fact which explains the apparent anomaly. In the first place, the demonstration is mainly intended to show that the phenomenon must be impossible if we still retain the ordinary theory in regard to the divisions of the retina and their functions. In the second place, experiment shows that our claim is correct: for, after long practice in combination by convergence or by divergence, those images which, according to construction, must fall upon disparate points, and which at first seemed to be single and to coincide, appear double until they are brought into the fovea. This indicates that they were never really fused into one. Why, then, is the fusion so apparent to vision? The answer is, that inhibition had suppressed such portions of one or both images contending for fusion, that the resultant, made up of complementary elements, appears as a single image. After considerable practice, the reflex and automatic tendency is weakened, and inhibition correspondingly decreases; so that the images which before seemed single appear double, as the law of disparate points requires.

Baltimore, Md., Jan. 4. J. H. HYSLOP.

Bacteriology as a Study in Schools.

THE subject of the study of bacteria, discussed by Professor Conn in a recent number of *Science* (xi. No. 257), is one which deserves more attention than it has attracted thus far, and I take the liberty of making a few suggestions which have presented themselves to an investigator rather than a teacher, but which may prove useful to the latter. Let us call the subject 'bacteriology' for convenience' sake, and drop the misleading expression 'germ-theory of disease,' which has had its day. We know, as positively as we know that the earth revolves on its axis, that certain diseases in man and animals are caused by the invasion and multiplication of bacterial parasites. There is no theory about this. The phrase is misleading, because it states that all disease may be due to germs, which is manifestly untrue.

There are several classes of students who would be greatly benefited by a careful study of bacteria in the laboratory.

1. Students of general biology and physiology would gain by a few simple experiments, readily performed, a very clear insight into the great metabolic activity of life in general, of bacteria in particular. It would be easy to demonstrate the formation of soluble ferments related to pepsin and diastase; the production of soluble and insoluble pigments, and the effect of re-agents upon them; the relation of vital activity to oxygen as expressed by aerobic and anaerobic germs; the effect of bacterial growth on various substances, such as blood serum, gelatin, and milk; the resistance of spores to high temperatures; the effect of disinfectants and antiseptics; the phenomena of phosphorescence, nitrification, and other equally interesting and instructive features of bacterial life. The habit of close observation and careful differentiation may be cultivated by the parallel study of two species as nearly alike as possible. All this, and more, can be done with bacteria obtainable at any time, from natural waters, from the soil, the digestive tract of mammals and other animals, from milk and various infusions. To impress the mind with the destructive effect of pathogenic forms, a rabbit, or mouse, or guinea-pig may be inoculated with some germ fatal to these animals, but harmless to man. Such a form, fatal to rabbits, is occasionally present in the mouth. The microscopic study of bacteria brings out facts of histo-chemistry, and features of the microscope itself hitherto scarcely known, which should be applied in ordinary histologic work.

2. There is another class of students who stand in need of such instruction. Much of the preparatory work of the student of medicine can and should be done at our higher institutions of learning. For instance, the admirable work done at Cornell University in preparing students for the study of medicine, of which I have personal knowledge, has always tended to push students into the front rank at the medical schools. These have no time to spare to teach students how to dissect well, how to study anatomy or to acquire the methods underlying histologic work and chemical analysis, nor have they the time to teach bacteriology. Yet no one should graduate in medicine to-day who does not know something about the secret working of this microscopic world, who cannot reason with it in his practice, or recognize the different forms when a diagnosis may be based upon them. Our biological laboratories may do much to help the medical schools in this direction. The physician will then be equipped with healthier ideas concerning the 'germ-theory;'